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3.6 STORAGE AND ADDITIONAL MANAGEMENT OPTIONS

Previous sections of this chapter have addressed many of the capabilities of the SFWMM on a region by region basis. This section will address the generic topic of simulation of storage in the model and will also describe some of the unique system management topics that have not been described to this point. The storage components covered in this section include: Large and Small Reservoirs, and Aquifer Storage and Recovery (ASR). The additional management options covered include: Best Management Practices, Wastewater Reuse and Operational Planning.

3.6.1 Storage Options

The primary types of storage simulated in the SFWMM are reservoirs and ASR. In the SFWMM, reservoirs are water holding systems that capture water either for later use or for the preservation of wetlands within the reservoir system. Aquifer Storage and Recovery is a water management technique in which water is stored underground in a suitable aquifer through a well during times when the water is available and recovered from the same well when needed. In the SFWMM, ASR systems are also considered to be reservoirs.

The SFWMM has the ability to model two types of above-ground reservoirs: small reservoirs that are modeled as separate entities within a grid cell; and large reservoirs that are equal to, or nearly equal to, a grid cell size and are not treated as a separate entity within the cell. For either type, the user has the option to specify basic design parameters, basic hydrologic connections, location, and operations. Reservoirs can be completely contained within a grid cell or across several grid cells. The model assumes all reservoirs to have vertical walls. It accounts for differences in the actual area of the reservoir and the area represented by the grid system, i.e., multiples of four square miles. Since rainfall and evapotranspiration depths are assumed to occur uniformly for each model grid cell, their effect on reservoir stage is transformed using a proportionality factor relating reservoir area and the area of the grid cell(s) where the reservoir is located. For a given reservoir:

$$sfactor = \frac{tot\_reservoirarea}{(no.\ of\ grid\ cells)(gridcellarea)} \qquad (3.6.1.1)$$

The change in reservoir stage within time step t is approximated using the following equation:

$$\Delta reservoirstage_t = \frac{RF_t - ET_t + LSEEP_t + GWIN_t}{sfactor} - (RF_t - ET)_t(1.0 - sfactor) \qquad (3.6.1.2)$$

where:

RF_t = rainfall into grid cell;
ET_t = evapotranspiration out of grid cell;
$LSEEP_t$ = levee seepage into grid cell; and
$GWIN_t$ = net groundwater inflow to grid cell

Reservoir stage is used in determining available storage in the reservoir. It is also the basis for calculating discharges through inlet and outlet structures (pumps and weirs). The primary operations associated with storage features tend to center around rules for transferring between adjacent basins or other storage facilities. Inflow and outflow to storage in the SFWMM can be related to a number of triggering mechanisms including:

- rising or declining adjacent canal stage;
- capture of local basin runoff;
- capture of releases from upstream storage;
- demand in downstream basins including agricultural water supply deficit, environmental water supply, etc. (quantified in a manner similar to that described for structure operations);
- projected long-term or short-term climate conditions (e.g. seasonally varying operations or pre-storm discharges);
- mitigation of high stages in above-ground reservoir (e.g. overflow prevention).

These triggered flows can be subject to a number of constraints including conveyance limitations, maximum storage capacity and coordination with other storage components (e.g. multiple sources associated with one objective). The interaction between storage features and various sub-regions with the SFWMM model domain is one of the unique aspects of the model. As an illustration of this feature, Figure 3.6.1.1 shows an example operational schedule for ASR wells associated with Lake Okeechobee. In this example, if LOK stage is above the Pulse release zone or if Lake Okeechobee stage is forecasted to be above the “ASR Injection” line within three months, Lake Okeechobee water is injected into ASR wells. For recovery during the dry season, water is retrieved from ASR wells if Lake Okeechobee stage is currently below, or is forecasted to be below in six months, the “ASR Recovery” line. During the wet season water is retrieved if LOK stage is below the “ASR Recovery” line and if the climate based inflow forecast is less than 1.5 million acre-ft for the next six months. The reader is reminded that these generalized operational strategies are used as an example of model capability only. Proposed operational rules for these features are continuously evolving with time as they go through brainstorming, field-testing and rule-making processes.

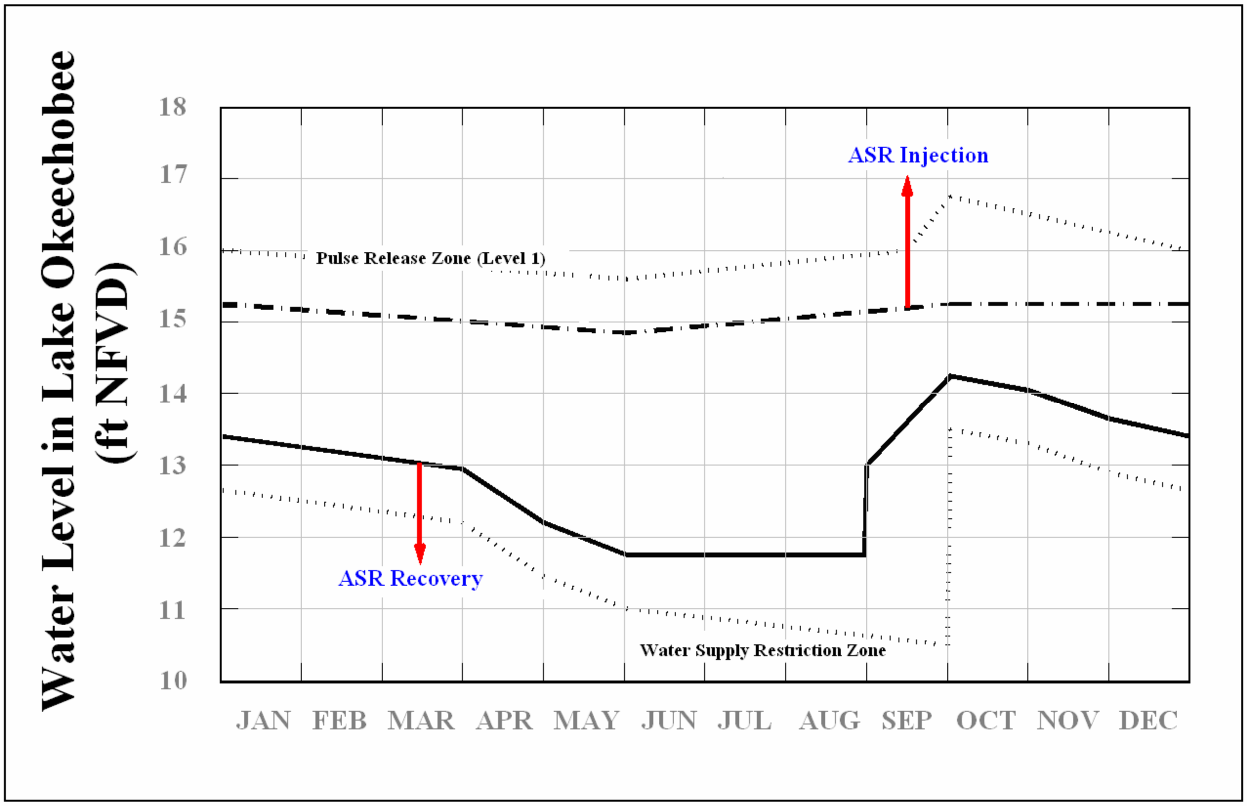

Figure 3.6.1.1 Example Trigger Lines for Proposed Lake Okeechobee Aquifer Storage and Recovery

Large Reservoirs

The simulation of large reservoirs can be categorized as follows:

- Managed Reservoir (e.g. STAs and EAA/LEC Reservoirs)
  - store water for later use;
  - actual area is important in modeling reservoir;
  - localized seepage losses can be simulated as a structural outlet.

- Unmanaged Reservoir (e.g. Holey Land)
  - leveed systems which store water that is not intended for later use;
  - approximate area is adequately defined by grid system.

The key modeling elements to be considered when simulating large reservoirs are as follows:

1. the cell(s) in the reservoir are grouped in a separate hydrologic basin;
2. any surface water flow from external cells to the reservoir cells is simulated with passive broad-crested weirs;
3. the reservoir stage equals the grid cell stage when ponding in the cell equals zero;
4. the flow intended for the reservoir is spread over the entire grid cell;
5. the mean stage for the area outside the reservoir (but within the reservoir grid cell) is calculated based upon an accumulated (over time) water budget for the area outside the

reservoir (when ponding in the grid cell is less than zero, the mean stage of the reservoir can not drop below ground level);

6. losses from the reservoir must be adjusted when the accumulated outflows exceed accumulated inflows for the area outside the reservoir; and
7. the reservoir land surface elevation and land use type must be the same as that in the grid cell.

The key modeling limitations of simulating a large reservoir are:

1. there can not be both a large and a small reservoir simulated in the same grid cell;
2. the model is sensitive to the reservoir's location within a grid cell only for levee seepage calculations;
3. the total recommended area of the reservoir must be no greater than 10 percent above the total grid cell area if the topography within the reservoir varies 0.5 feet or greater compared to neighboring cells.

The reservoirs are often designed to operate with a passive weir outflow. In those cases, the calculations will handle hydrologic conditions when the ponding depth in the reservoir is higher than the tailwater condition of the weir, even if the tailwater depth is greater than the height of the weir.

The order of computations, for a daily time step, is as follows:

1. the levee seepage calculations;
2. the reservoir depth adjustments for inflows to the reservoir which may come from the Lake or from a canal;
3. the overland flow, ET, and infiltration calculations;
4. groundwater flow and residual infiltration calculations;
5. the reservoir outflow determination based on the specified operation (weir or target delivery);
6. the reservoir storage calculations; and
7. the daily values written, if desired by user.

Small Reservoirs

Small reservoirs are treated as separate entities (for stage and water budget purposes) from the cell(s) in which the reservoir is placed. The primary function of small reservoirs is to treat and either redistribute or attenuate flows. Examples of small reservoirs would include STA 6 (which treats the inflow) or the C-111 Buffer Strip reservoirs (which redistribute and attenuate inflows). An example of a small reservoir that redistributes flow would be the proposed ACME Basin reservoir. The first check performed by the model to see if the reservoir can be treated as a small, separate entity is the size ratio of reservoir to cell area as input by the model user. If the size ratio is greater than the input value (typically 0.6), the reservoir should be treated as a large reservoir. A reservoir can be considered small even if the reservoir spans two or more cells, but the size ratio in any one cell should be less than the input value.

The key modeling considerations when simulating small reservoirs are:

1. cells containing a reservoir do not have to be grouped in a separate hydrologic basin;
2. overland flow can be simulated through a reservoir cell in a similar manner to that in remaining cells;
3. the reservoir stage is independent of grid cell stage;
4. groundwater interaction with the grid cell is via a seepage rate;
5. inflow destined for the reservoir enters the reservoir directly;
6. the mean stage for the area outside a reservoir (within the cell) is simply groundwater level plus ponding;
7. no area adjustment in losses from the reservoir is necessary;
8. reservoir land surface elevation and land use type can be different from that in the grid cell; and
9. one-dimensional overland and groundwater flow within long narrow reservoirs can be simulated (independent of the grid cell).

There are two principal inflows to small reservoirs: direct structural inflow and direct rainfall. Outflows can be structural or non-structural (e.g. seepage). When a multi-cell, narrow reservoir is modeled, it must have a linear arrangement. In those cases, an equation (similar to Manning's equation, but based on effective roughness) is used for one-dimensional flow, flow is computed in a 6-hour time step and the flow width is assumed to be equal to the reservoir width.

The order of computations, for a daily time step in a small reservoir, is similar to that of the large reservoirs (presented earlier). However, after the calculation for groundwater flow and infiltration, there are two routines specifically written to handle small reservoir overland flow and to handle groundwater flow.

Aquifer Storage and Recovery

Although the use of Aquifer Storage and Recovery (ASR) in South Florida is only in its infancy, ASR is a viable water management feature for the region. The popularity of ASR can be seen in Figure 3.6.1.2 (adapted from ASR Systems LLC, 2004) in a measles map – which, over time, shows a growing trend in red dots (new ASR sites). The ability to model ASR was included in the SFWMM to allow for evaluations of the potential application.

The potential uses of ASR in South Florida include: (1) provide additional regional storage while reducing both evaporation losses and the amount of land removed from current land use (e.g. agriculture) that would normally be associated with construction and operation of above-ground storage reservoirs; (2) increase Lake Okeechobee's water storage capability to better meet regional water supply demands for the Everglades, for agriculture, and for the Lower East Coast urban areas; (3) manage a portion of regulatory releases from the Lake Okeechobee primarily to improve Everglades hydropatterns and to meet supplemental water supply demands of the Lower East Coast; (4) reduce harmful regulatory discharges to the St. Lucie and Caloosahatchee Estuaries; (5) maintain and enhance the existing level of flood protection; and (6) for improvement to Lake Okeechobee water levels.

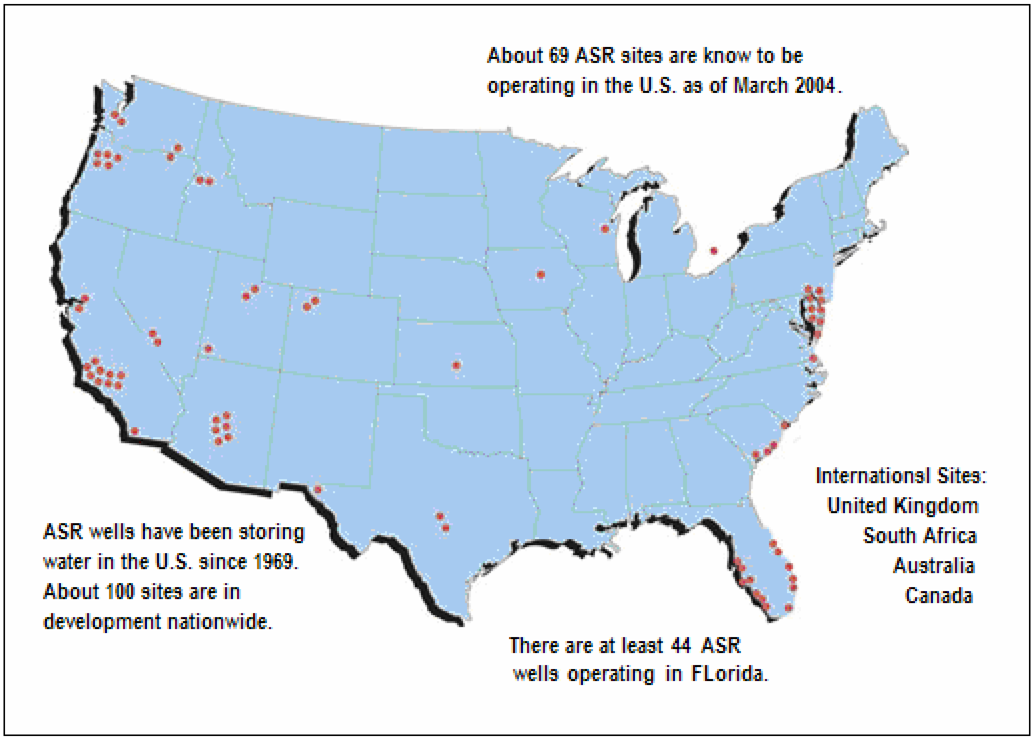

Figure 3.6.1.2 Measles Map Showing Spread of Aquifer Storage and Recovery Wells (Adapted from ASR Systems LLC, 2004).

The SFWMM simulates ASRs by performing a simple water budget on the amount of injected water (assumed to be well below the surficial aquifer) taking into consideration inefficiencies in injection and withdrawal phases of the operation, and basically treating an ASR as a regular reservoir with one obvious difference: ASRs do not lose water via evapotranspiration which is significant in above-ground reservoirs.

In the SFWMM, several forms of ASR are simulated. One form is utility ASR where groundwater is pumped down from the surficial aquifer to the deeper confined aquifer using municipal utilities as the source during the wet season and later retrieved by the municipal utilities to help meet urban needs during the dry season. This is simulated in the SFWMM by simply altering the municipal wellfield data file, which includes increasing pumpage from the surficial aquifer during the wet season and decreasing pumpage during the dry season for the affected wellfields, taking into account the capacity of the utility ASR, and the efficiency in retrieving the water from the utility ASR.

Other forms of ASR simulated are in association with excessive canal flow, local reservoirs, and/or Lake Okeechobee. Pumpage down to ASR is simulated as an additional outlet from the appropriate source. Water recovered from ASR is routed to the appropriate destination. The efficiency of ASR retrieval is controlled by input options, but is typically assumed to be 70%. The net accumulation of excess water injected into the deep aquifer, known as the ASR bubble, is assumed to have no minimum or maximum limit in size unless specified by the user. The ASR bubble size, which is updated on a daily basis, can be a limiting factor in ASR recovery during extended drought periods when there is little or no water left to recover.

ASRs can potentially be placed anywhere within the modeling domain of SFWMM, however several areas have been pre-defined in the model. These areas are: around Lake Okeechobee, the Caloosahatchee Basin with reservoir, along the C-51 canal, several areas (associated with reservoirs) in Palm Beach County; and in the Site 1 reservoir and along the Hillsboro Canal (along the border of Palm Beach County and Broward County). Additionally, a utility ASR well field is located in Miami-Dade County. Other ASR facilities could be added to the model as needed.

3.6.2 Additional Management Options

Best Management Practices

As part of the Everglades Forever Act (Florida Statutes, Chapter 373.4592, 1994) requirements, Best Management Practices (BMPs) have been implemented in the Everglades Agricultural Area (EAA). The objective of BMP implementation in the EAA is to improve water quality in the Everglades Protection Area (EPA) by reducing phosphorous loads.

As a result of BMP implementation, there is an expected runoff reduction from the EAA. The Everglades Forever Act required that the District develop a model to quantify the amount of water to be replaced from Lake Okeechobee to the EPA. District Rule Chapter 40E-63, F.A.C., Part II adopted on October, 1995, established the model for the quantification of runoff reduction during a water year and replacement water to be delivered from the Lake to the EPA from October to February of the next water year. The replacement water was based on data from the 1979 to 1998 base period.

Since BMP replacement water deliveries are a function of rainfall, time series of BMP replacement water spanning the period of simulation (1965-2000) are required. Due to the lack of historical data spanning the 1965-2000 period of simulation, a rainfall-based approach has been used to estimate BMP replacement water time series for the entire period of simulation. The method is based on the strong ($R^2 = 0.97$) logarithmic relationship between EAA average rainfall for water years 1995-2000 and the historical replacement water target for water years 1996-2001 (Figure 3.6.2.1). EAA average rainfall is a weighted-average of rainfall at 9 District monitoring stations defined in Rule Chapter 40E-63 (Table 3.6.2.1).

There are two main reasons for the selection of water years 1995-2000 to assemble the model used here: (1) the 2000 Base simulation should reflect full BMP implementation which was completed around 1995, and (2) water years 2001 and 2002 were excluded due to the extreme drought conditions and water shortages affecting South Florida. For implementing the method, rainfall for nine SFWMM grid cells (Table 3.6.2.1), representing the nine District monitoring stations, was extracted from the SFWMM input rainfall binary file. EAA nine-cell average rainfall was calculated based on the Thiessen weights defined in Rule Chapter 40E-63, which are listed in Table 3.6.2.1. Figure 3.6.2.2 shows that the EAA nine-cell average rainfall for water years 1979-2000 very closely matches the EAA nine-station average rainfall ($R^2 = 0.99$) as expected.

Based on the logarithmic relationship shown in Figure 3.6.2.1 (adapted from Abtew, 2002), the EAA average rainfall obtained from the SFWMM rainfall binary file for water years 1965-2000 was used to estimate target replacement water deliveries for the next water year (Table 3.6.2.2, Figure 3.6.2.2).

Rule Chapter 40E-63 defines fixed monthly percentages of the target replacement water to be delivered to the EPA during October to February of the next water year (Table 3.6.2.3). These monthly factors were applied to the estimated target replacement water deliveries for a water year to obtain monthly target deliveries. January-February, 1965 and October-December, 2000 target deliveries were estimated circularly based on the estimated target replacement water deliveries for a water year made up of the combination of 2000 and 1965 data. For creating the daily time series of replacement water, monthly target deliveries were uniformly distributed throughout the month. Actual replacement water deliveries may be lower than the target given by the Rule due to canal conveyance limitations or the Water Conservation Areas (WCAs) exceeding their regulation schedules. In addition, makeup water deliveries may be suspended when the Lake is under supply-side management.

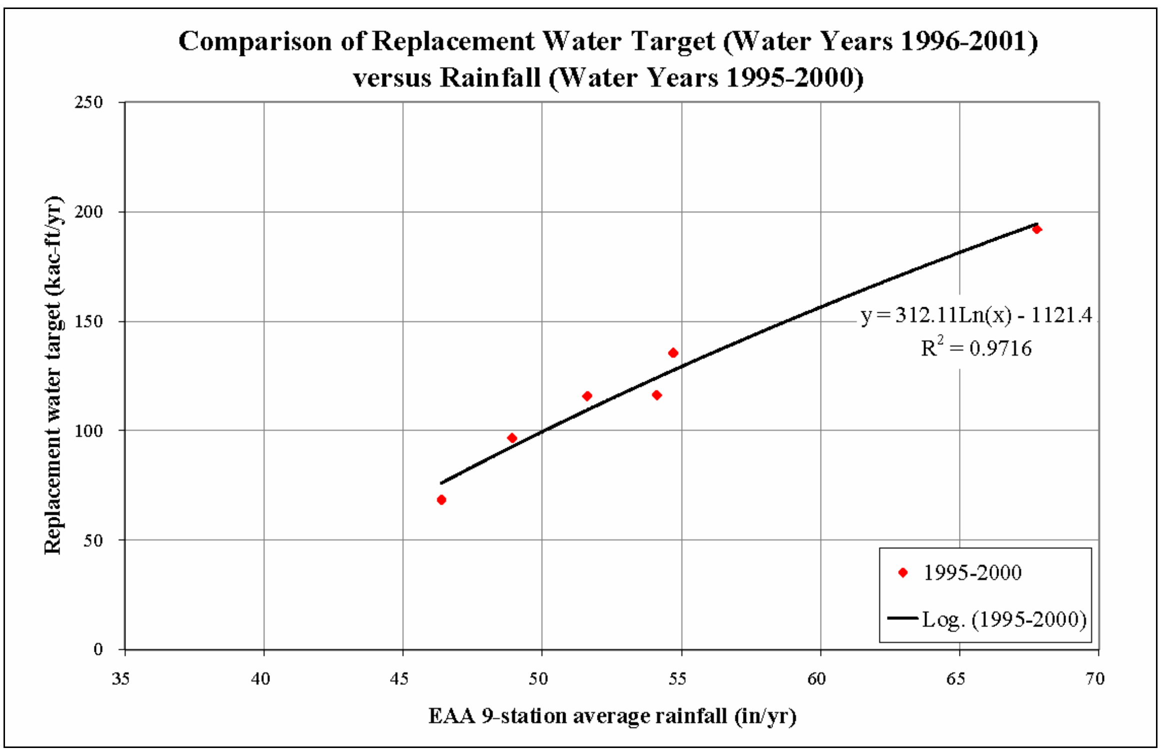

Figure 3.6.2.1 Logarithmic Relationship between EAA Nine-Station Average Rainfall for Water Years 1995-2000 (Adapted from Abtew, 2002).

Table 3.6.2.1 District's Rainfall Monitoring Stations in the EAA used in BMP Replacement Water Calculations

STATION	Thiessen Weight	DBKEY	XCORD	YCORD	SFWMM cell (Row, Col)
ALICO	0.0974	15197	662050.191	792096.255	(48,11)
BELLE-GLADE	0.1617	15200	777082.691	844670.746	(53,22)
MIAMI LOCK_R	0.1076	15198	719458.180	853630.902	(54,17)
PAHOKEE1_R	0.1438	15201	798481.181	901482.752	(58,24)
S5A_R	0.0989	15202	862679.587	855002.715	(54,30)
S6_R	0.0763	15203	837525.021	777745.664	(46,28)
S7_R	0.0592	15204	807896.812	728054.542	(42,25)
S8_R	0.1743	15205	730112.505	726534.776	(42,18)
SOUTH BAY_R	0.0844	15199	753759.327	847537.884	(53,20)

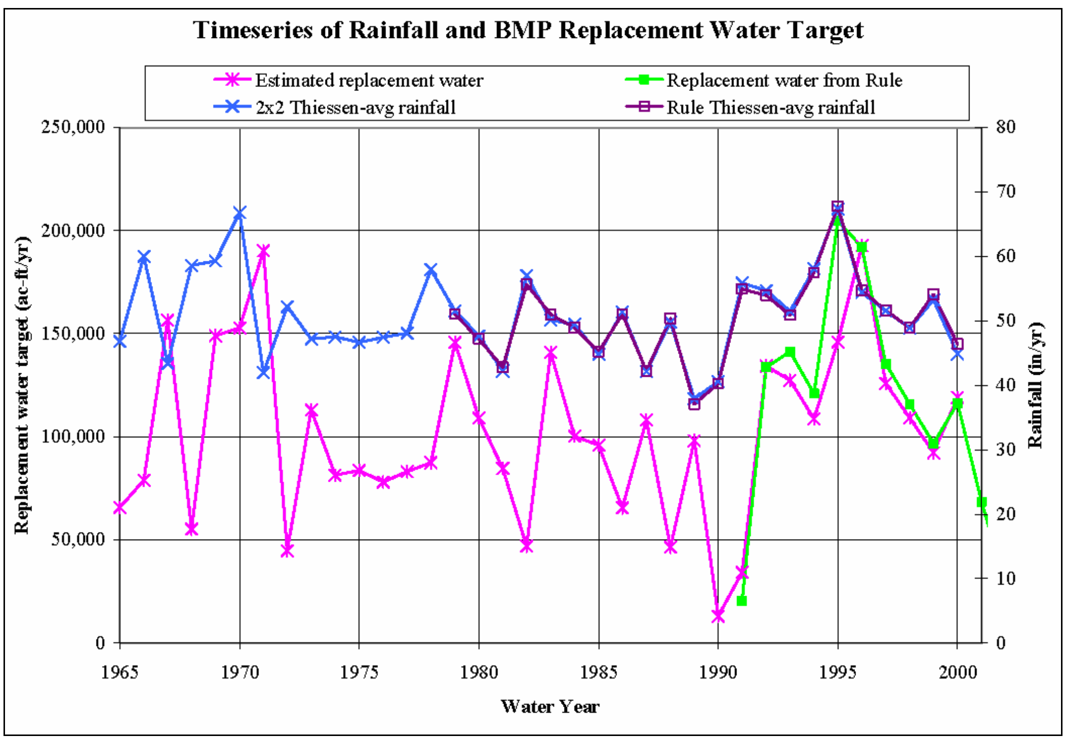

Figure 3.6.2.2 Annual Time Series of EAA Nine-Station Average Rainfall from BMP Rule

Note: Calculations used EAA 9-cell average rainfall from SFWMM rainfall binary, replacement water from BMP Rule and estimated replacement water for SFWMM. There is a one year lag between rainfall and BMP replacement water.

Table 3.6.2.2 Statistics of the Estimated BMP Replacement Water Target Time Series by Water Year

Water Year	Water Year Rainfall (in/yr)	Estimated BMP Replacement Water Target (ac-ft/yr)
1965	46.8	65,747
1966	60.0	78,942
1967	43.4	156,480
1968	58.6	55,167
1969	59.3	149,082
1970	66.8	152,755
1971	41.9	190,077
1972	52.2	44,743
1973	47.2	112,976
1974	47.5	81,451
1975	46.7	83,625
1976	47.4	78,034
1977	48.1	83,043
1978	58.0	87,492
1979	51.5	145,702
1980	47.7	109,023
1981	42.2	84,694
1982	57.1	46,860
1983	50.1	140,917
1984	49.4	100,290
1985	44.8	95,910
1986	51.4	65,409
1987	42.2	108,120
1988	49.8	46,430
1989	*Min: 37.9*	98,161
1990	40.6	*Min: 13,058*
1991	55.9	34,296
1992	54.7	134,301
1993	51.5	127,463
1994	58.0	108,723
1995	*Max: 67.4*	145,978
1996	54.4	*Max: 192,673*
1997	51.5	125,889
1998	48.9	109,099
1999	53.2	92,337
2000	44.9	119,143
Average for base period (water years 1979-1988)	48.6	89,581
Average for 36-yr period of simulation (1965-2000)	50.8	101,780

Note: The base period includes water years 1979-1988 prior to BMP implementation. The BMP Replacement Water Rule was developed based on observations for the base period. Note the one year lag between rainfall and BMP replacement water. For example, rainfall for water year 1981 includes rainfall from October, 1980 to September, 1981. Rainfall for water year 1981 is used to estimate BMP replacement water target for delivery from October to February of the next water year (water year 1982: October, 1981-February, 1982).

Table 3.6.2.3 Monthly Distribution Target Percentages for BMP Makeup Water Deliveries

Month of Water Year	Target Percentage
October	28.7%
November	22.8%
December	26.5%
January	14.9%
February	7.1%

Wastewater Reuse

The wastewater reuse concept is associated with the advanced treatment of wastewater to make it suitable for environmental or groundwater release. Reuse was identified as a possible source of water in the Comprehensive Everglades Restoration Plan (CERP) in several specific areas; however the model has the ability to include reuse in any grid cell. The inflows are specified by the user and can be input on a monthly-average basis. The source of the water is assumed to come from a source currently removed from the system, (e.g. by deep-well injection) but is redirected as a source of new water. The reuse water can be introduced back into the system at either a grid cell or canal location.

Operational Planning

The SFWMM normally runs in a planning tool mode to establish existing or base conditions. The existing or base conditions can be used to determine such metrics as National Environmental Policy Act (NEPA) baseline requirements, existing levels of service or water reservations analysis. However, the model can also be run as an operational planning tool. In the operational planning mode, it can be used to support real-time operational decisions. When the model is run in the operational planning mode it is referred to as Position Analysis (Cadavid, et al. 1999). In South Florida, droughts and floods occur over relatively long periods of time due to the slow-paced hydrology. As a result, the Position Analysis (PA) provided by the SFWMM can be useful in predicting potential results of real-time operations over the next several months based on modeling outputs from past hydro-meteorological events (or predicted historical traces). Because actual historic data does not represent the system as is operated today (or in its current configuration of structures), model predictions are used to create the simulated response of the modeled system to historical climate conditions (Obeysekera, et al. 2000). This ensures that the current (or proposed) operations are accounted for in the analysis when using past hydro-meteorological data. There are two kinds of PA runs: Conditional (which incorporates climate forecasts) and Unconditional (which is based only on the historical climate data).

In PA mode, all the storage areas in the model are initialized to current conditions for each of the 36 years in the 1965-2000 simulation period. Once the initial conditions are set, the model simulates, under different climatological input scenarios and current operational practices, different outcomes (stage and flow) of the system for the ensuing 12-month period. Establishing existing conditions as the initial condition for a model is a daunting task given the difficulties of having to determine several parameters such as storage volumes in reservoirs, stages in canals and lakes, soil moisture levels, groundwater levels, and inflows (including flow predictions for the Kissimmee River). In order to accomplish this condition, collected raw data at gage sites are compared to snapshots (from SFWMM runs) to find a similar condition. Statistical analysis of these snapshots is used in selecting an initial grid condition such as shown in Figure 3.6.2.3.

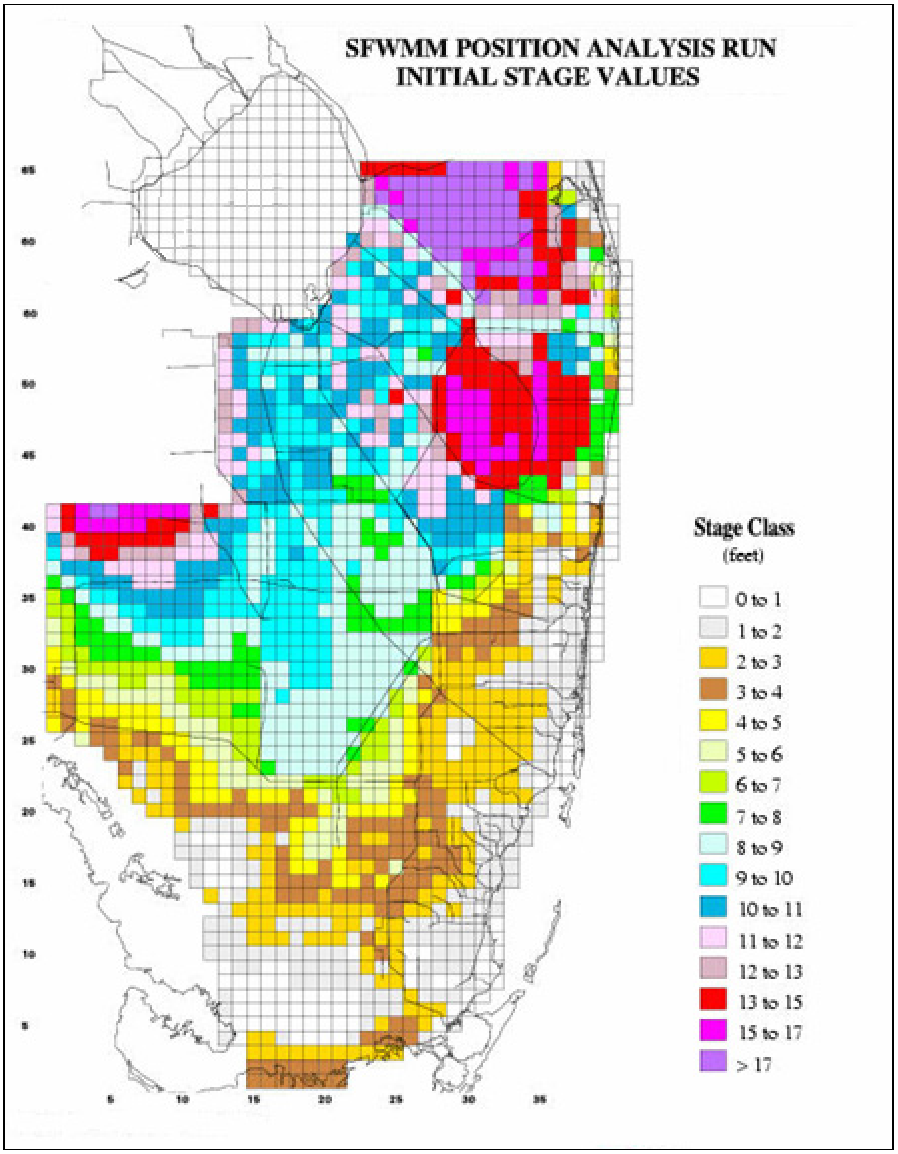

Figure 3.6.2.3 SFWMM Grid Values of Initialized Stage

Once the initial conditions input have been developed, the SFWMM begins a 36-year simulation. When the starting month is reached after each year of simulation, the run is re-initialized to the starting conditions. Without the re-initialization the resulting stage prediction output for Lake Okeechobee appears as shown in Figure 3.6.2.4. With the re-initialization, the stage prediction output appears as shown in Figure 3.6.2.5. By processing the historical traces, probabilities can be developed and associated with each yearly prediction (also shown in Figure 3.6.2.6). Such predictions are a special form of risk analysis. When a new climate forecast is input into the model, a conditional PA run is made. An example of the change that might occur between a conditional and unconditional run is shown in Figure 3.6.2.6.

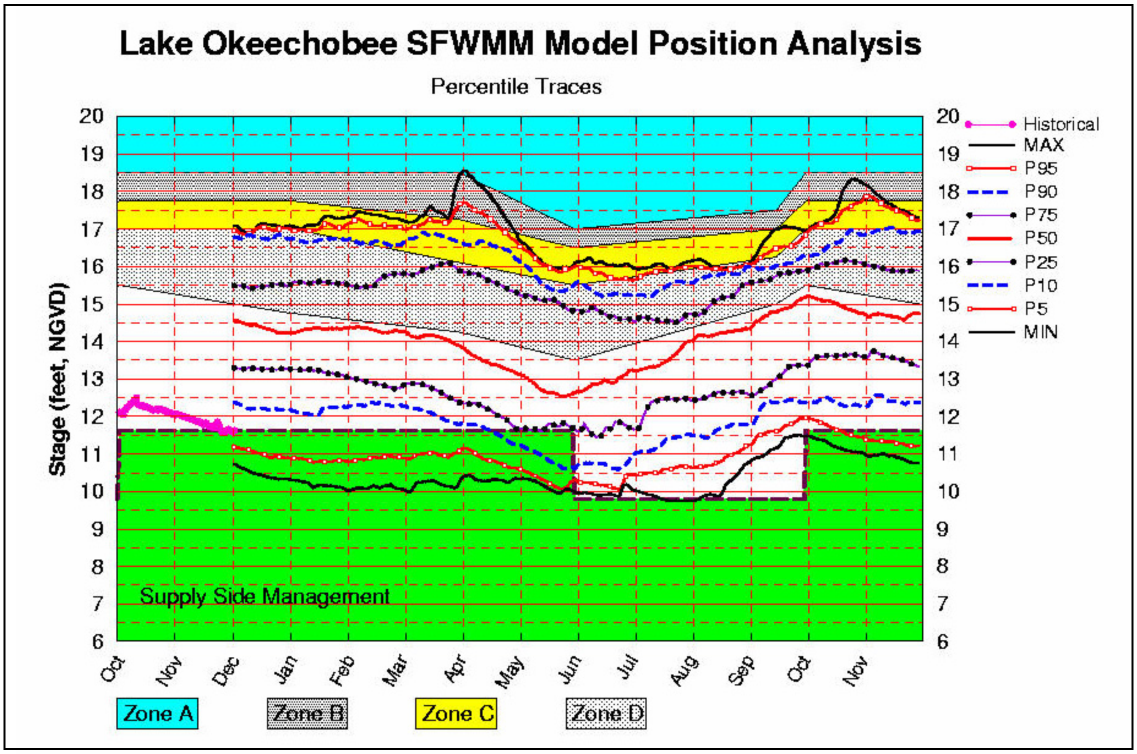

Figure 3.6.2.4 Historical Traces of Stage Predictions in Lake Okeechobee

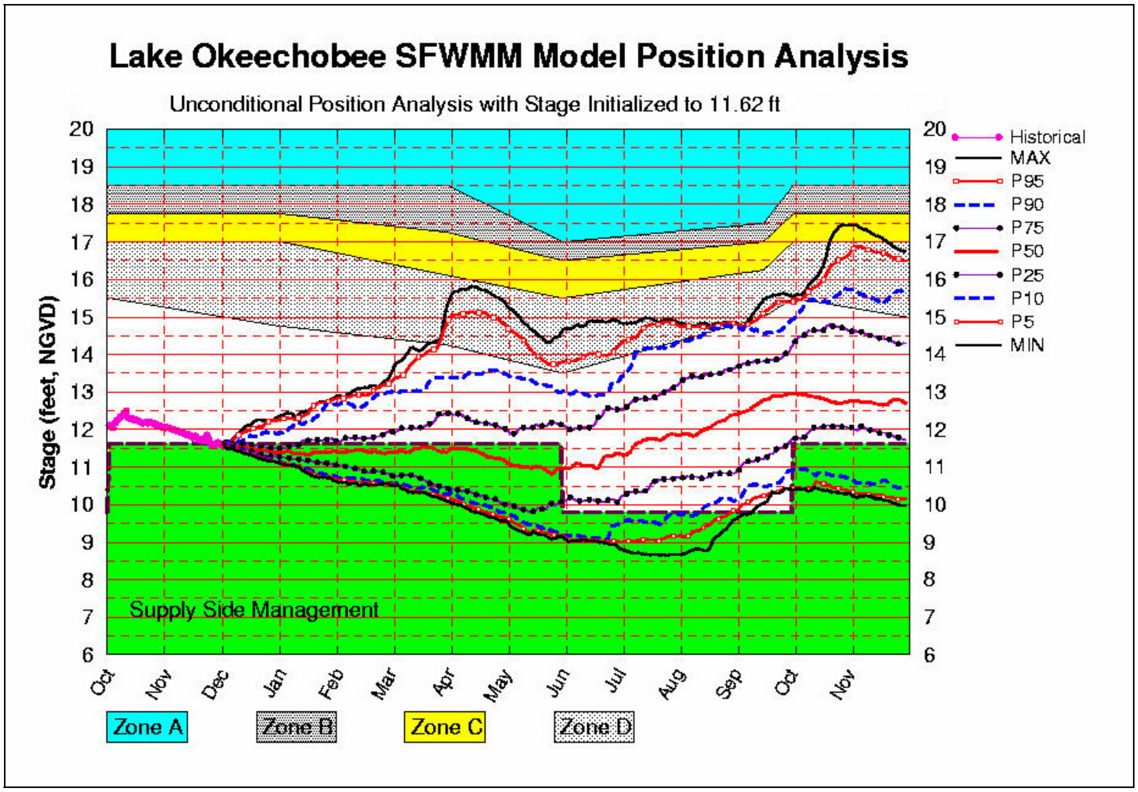

Figure 3.6.2.5 Historical Traces Re-Initialized to Starting Conditions for Lake Okeechobee

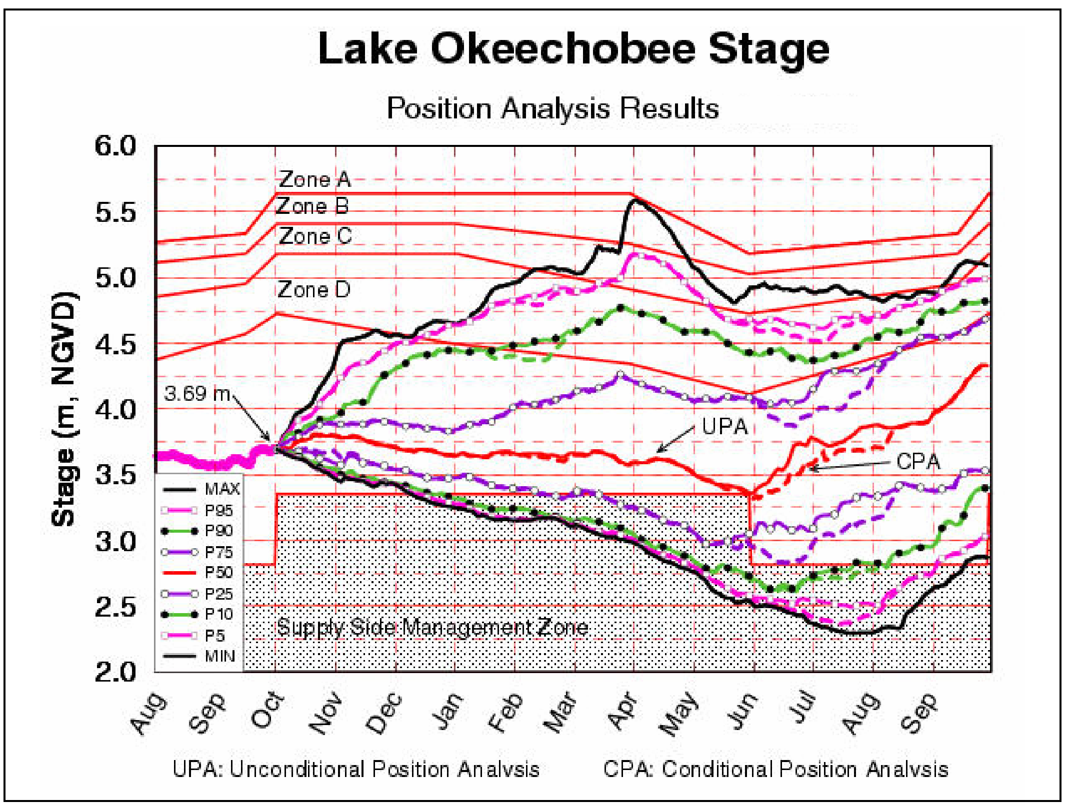

Figure 3.6.2.6 Conditional and Unconditional Position Analysis Stage Predictions for Lake Okeechobee